Cavity Beam Position Monitor Systems for the Interaction Point at Accelerator Test Facility 2

Y. I. Kim, H. Park (*KNU*)
S. T. Boogert, A. Lyapin (*RHUL*)
J. Frisch, D. McCormick, J. Nelson, T. Smith, G. R. White (*SLAC*)
M. Ross (*FNAL*)
H. Hayano, Y. Honda, T. Naito, R. Sugahara, N. Terunuma, T. Tauchi, J. Urakawa (*KEK*)

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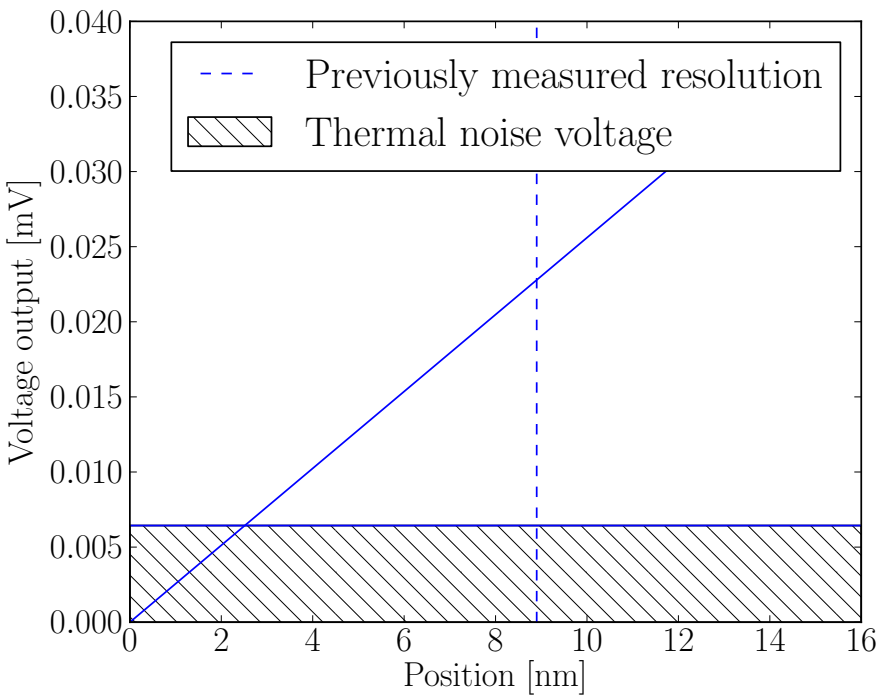
Motivation



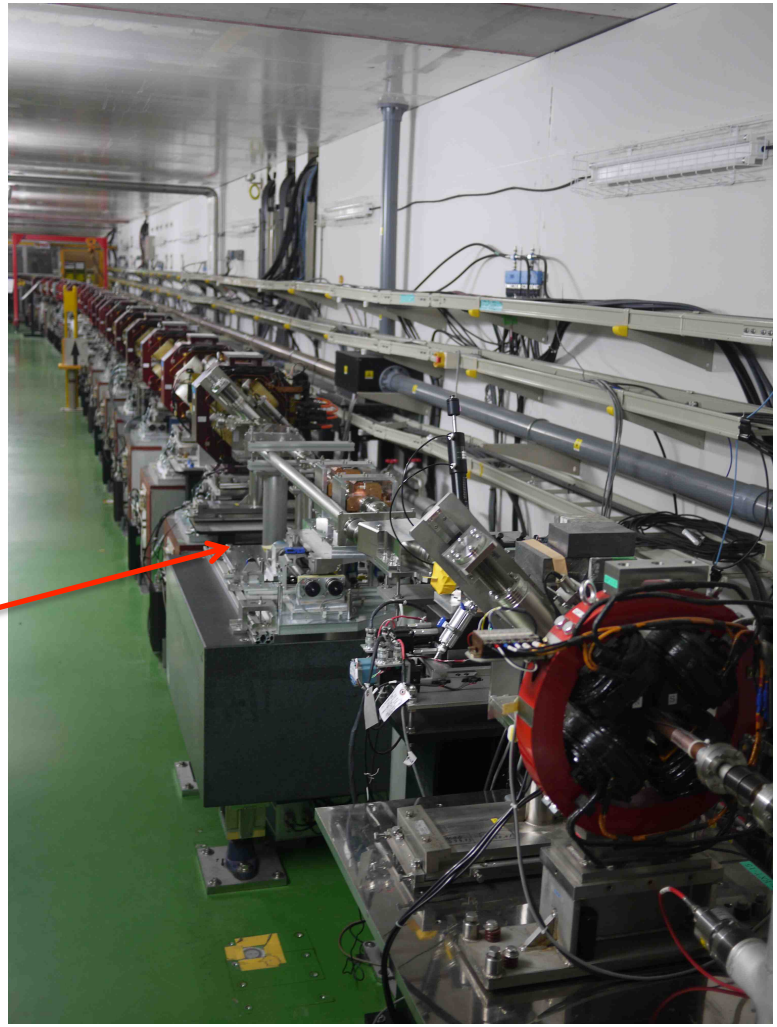
- Two goals at ATF2
  - Goal 1 : To achieve 37 nm beam size vertical plane
  - Goal 2 : Stabilize the beam focal point at a few nanometer level
- Previous result : 8.9 nm
  - Expected resolution was 2.6 nm at the nominal beam charge (1×10^{10} electrons/pulse)
- Need to understand unknown noise for achieving few nanometer position resolution

Accelerator Test Facility 2

2011 Nov. ~ Dec.

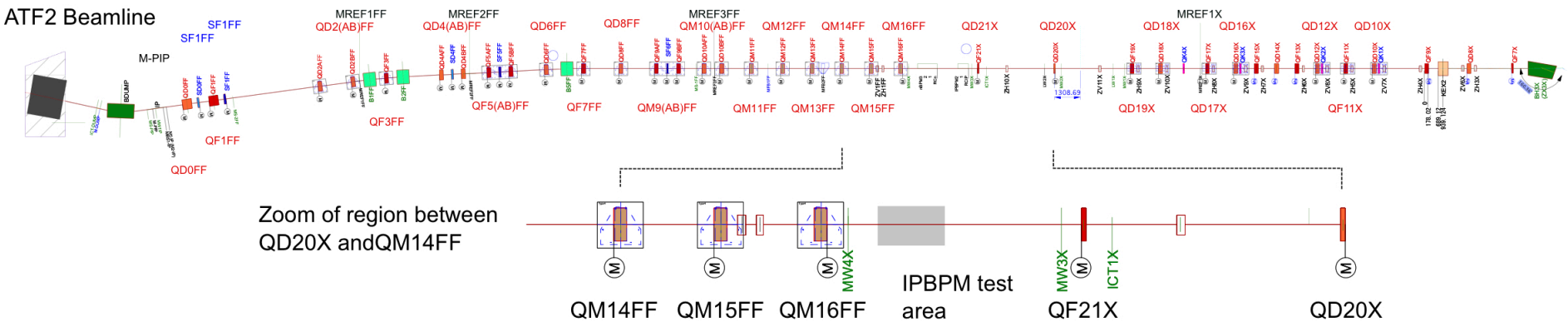
Interaction point

IPBPM test location



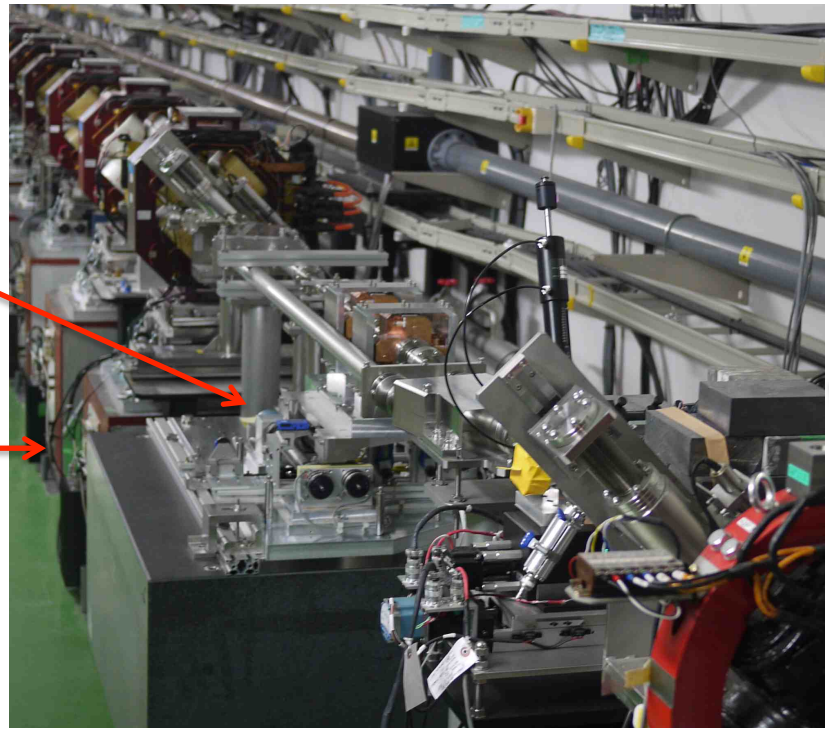
From damping ring

IPBPM test system location



Cam mover system

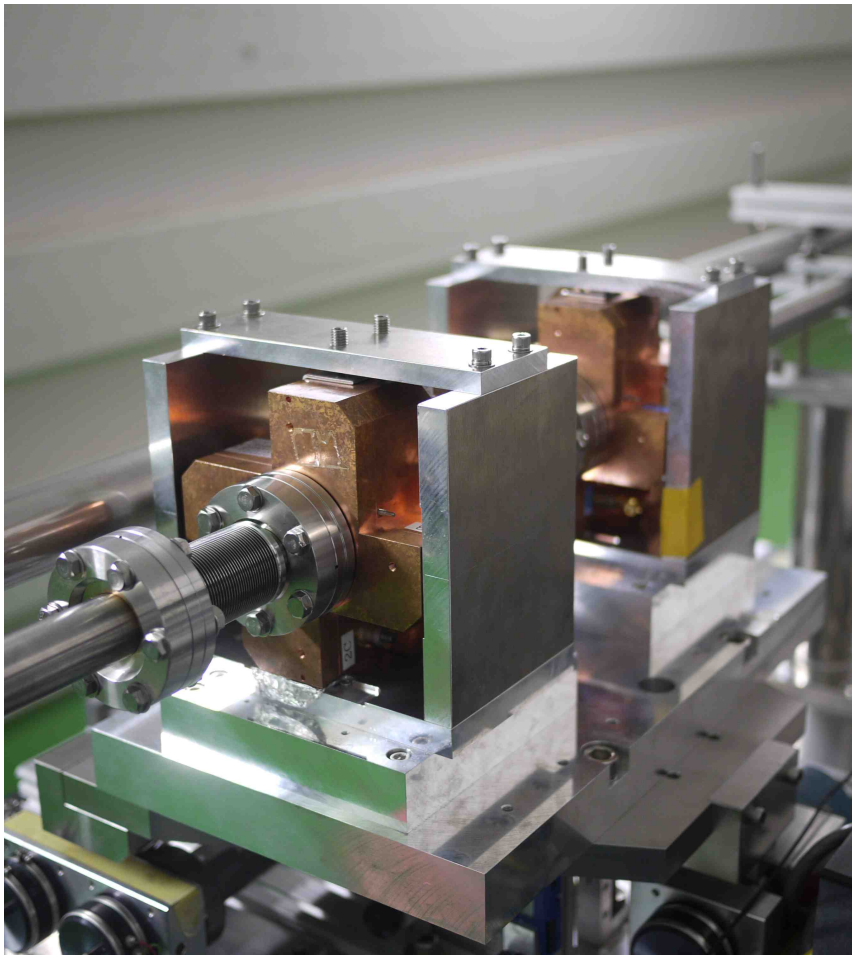
Granite table



Electronics hidden near floor

Electron beam direction

Interaction point BPM (IPBPM)



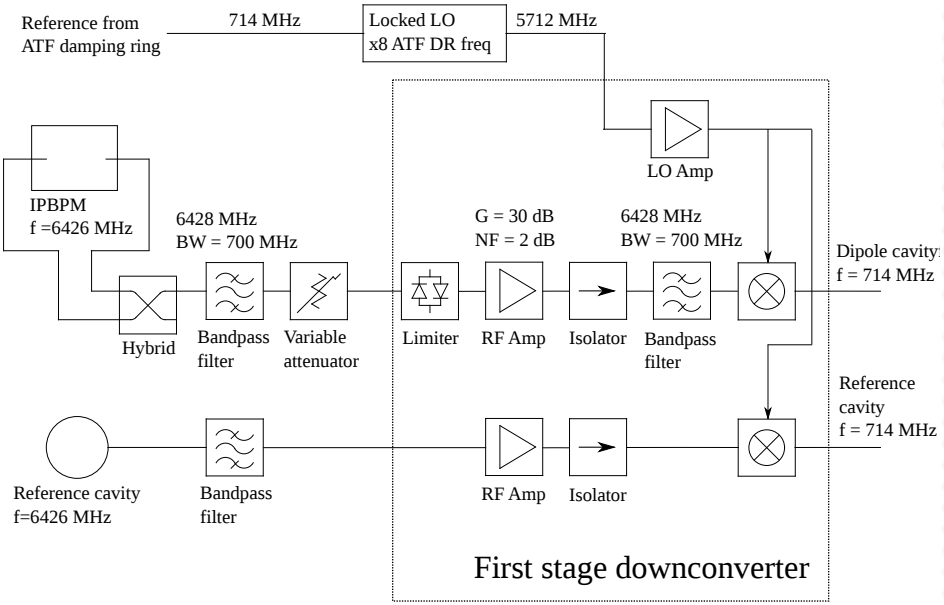
- Rectangular cavity shape
  - To measure beam position in X direction and Y direction, independently with single cavity
- Short cavity length in the z direction
  - Low angle sensitivity
  - Since large angle jitter due to the strong focus at IP
- Ultra high position sensitivity
  - In order to measure nanometer beam offset

Electronics

First stage

C –band -> 714 MHz

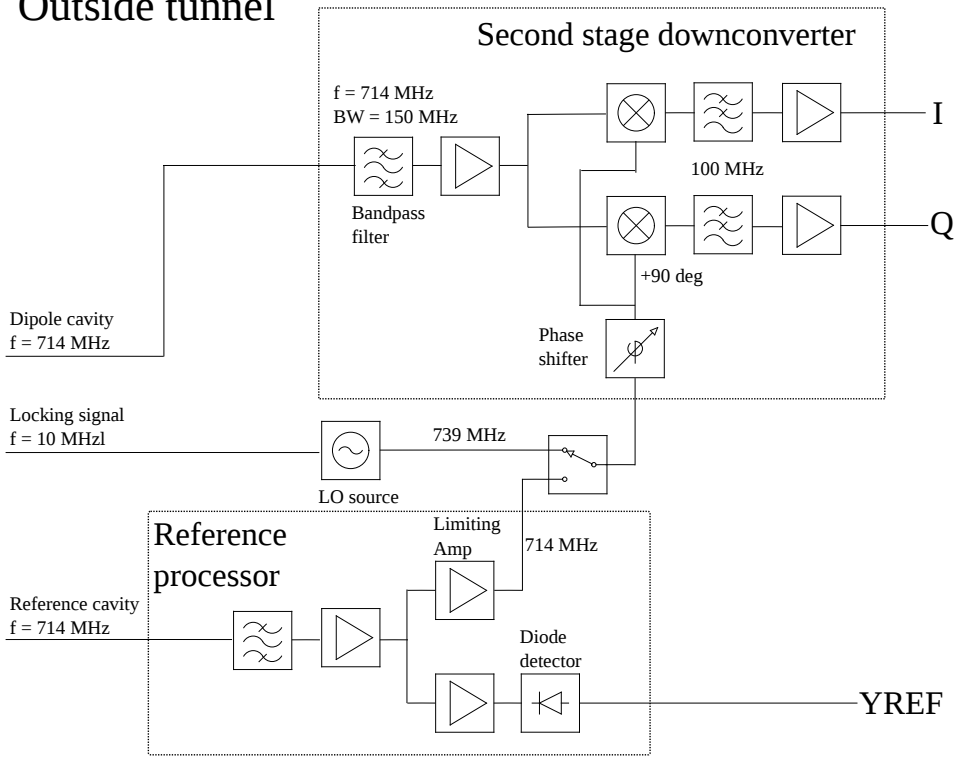
ATF2 tunnel system



Second stage

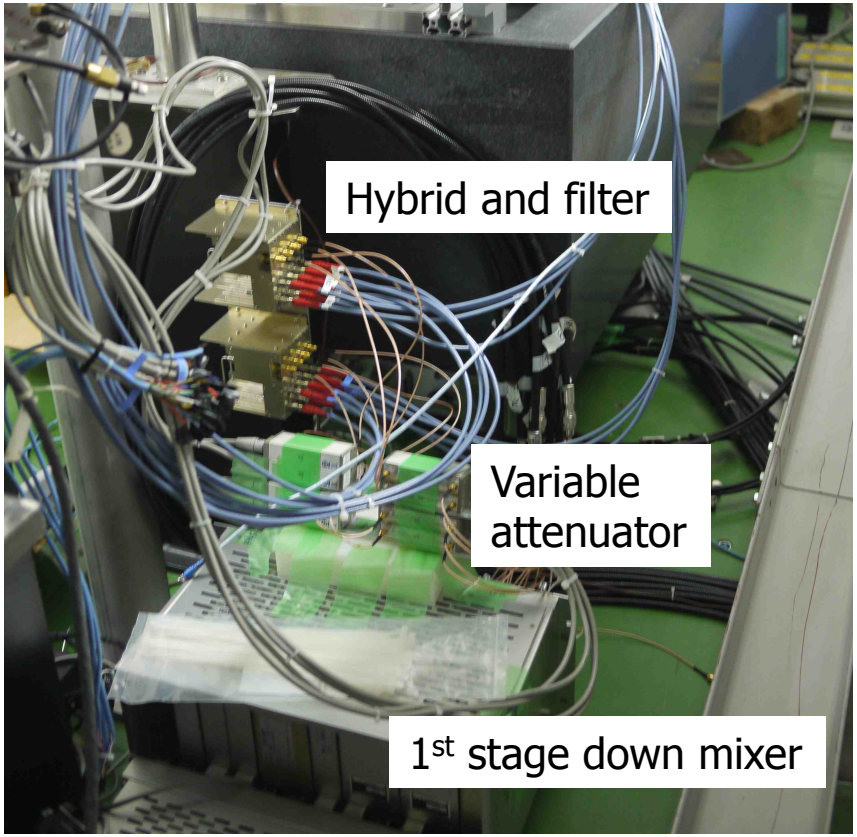
714 MHz -> baseband or 25 MHz

Outside tunnel

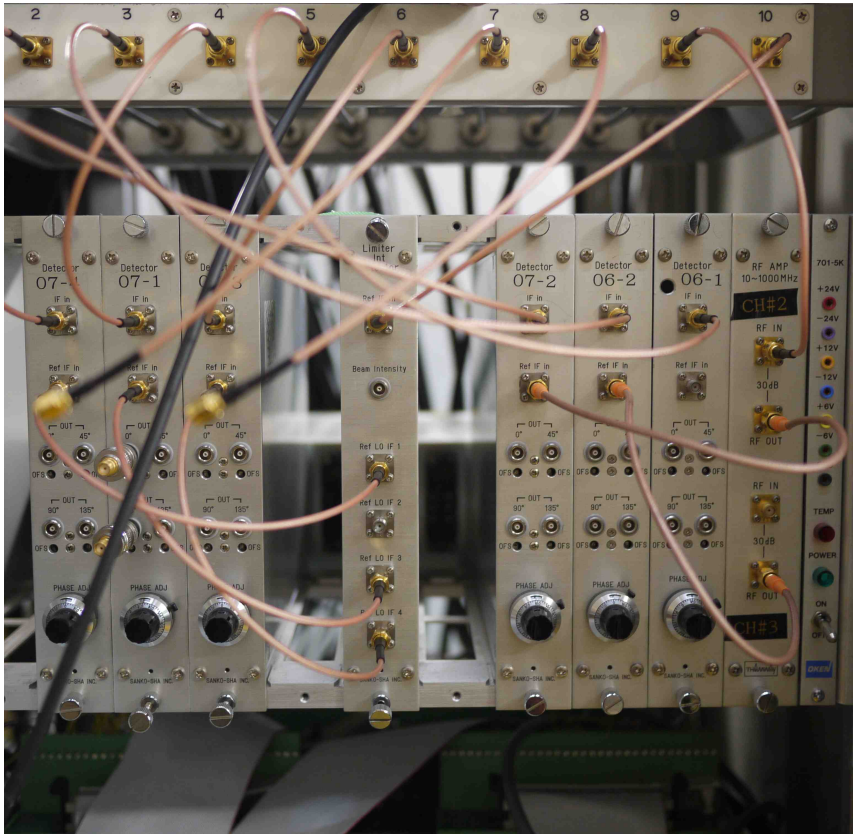


Hardware installation

First stage of down mixer (C-band - > 714 MHz)
@ in the tunnel



Second stage of down mixer (714 MHz -> I, Q)
@ the outside of the tunnel



Data taking

Three, 8 hour ATF2 shift per week over three weeks (2011. Nov. ~ Dec.)

Label		
W1-HO-CA-RA	Homodyne	
W1-HO-CA-RA-C	Homodyne	Varied bunch charge
W1-HO-CA-RA-B	Homodyne	Varied bunch length
W2-HO-CA-RA	Homodyne	
W3-HE-CA-RA	Heterodyne	
W3-HE-CA-RA-C	Heterodyne	Varied bunch charge

WN : N is Week number

HO/HE : Homodyne/Heterodyne

CA : Calibration attenuation value in dB

RA : Resolution attenuation value in dB

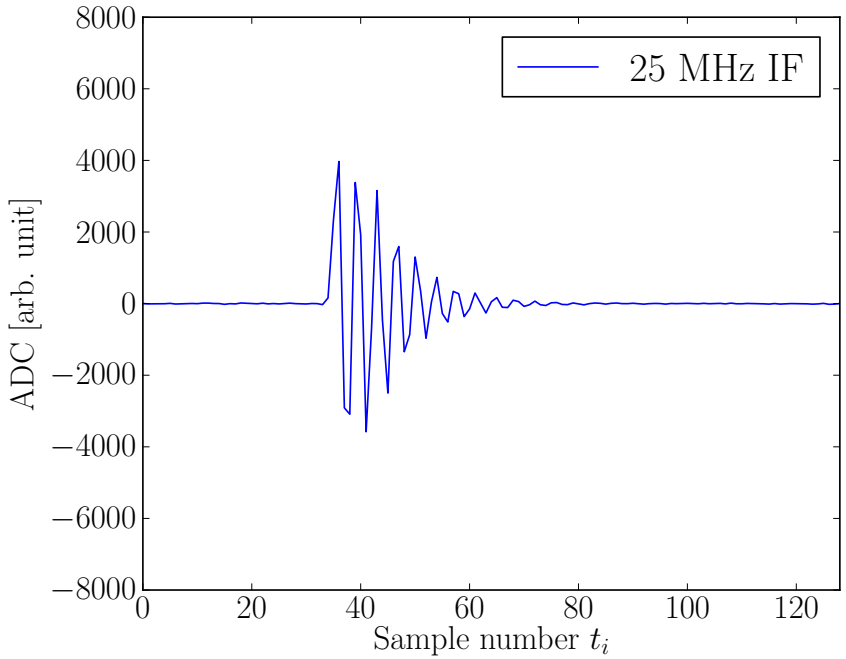
C/B : Charge scan, Bunch length scan

40, 30, 20 dB attenuator for calibration

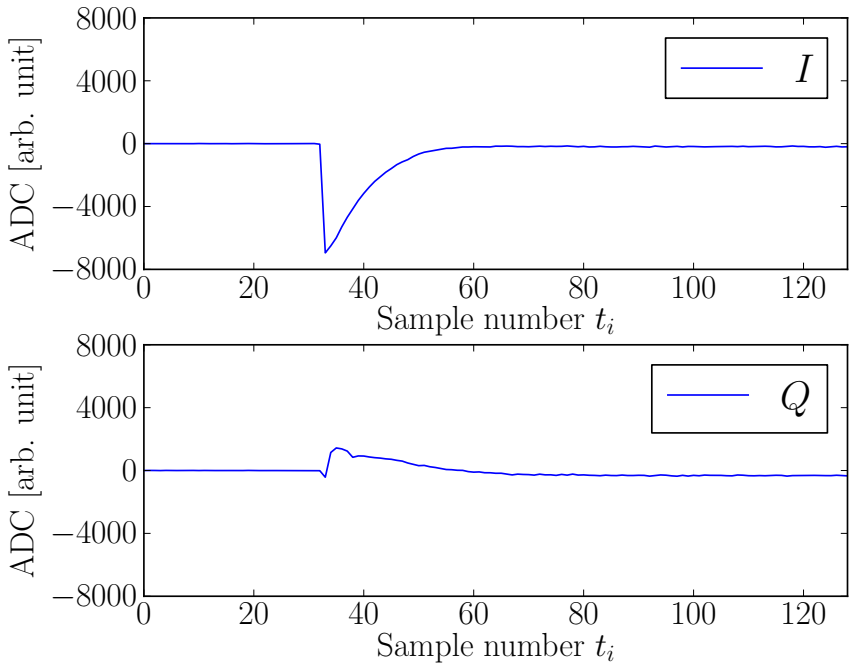
40, 30, 20, 0 dB attenuator for resolution

Heterodyne/Homodyne

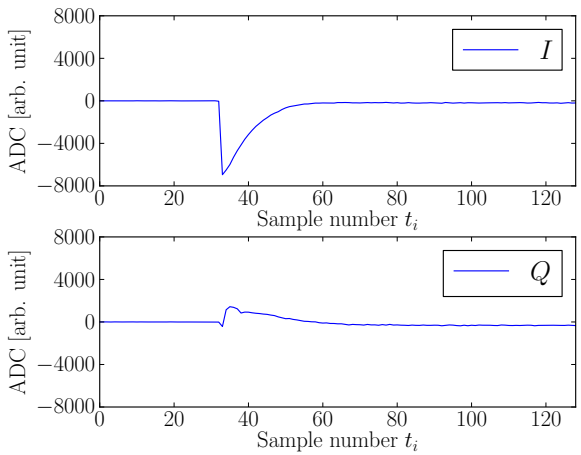
Heterodyne processing digitized Signal (Non-zero IF signal)

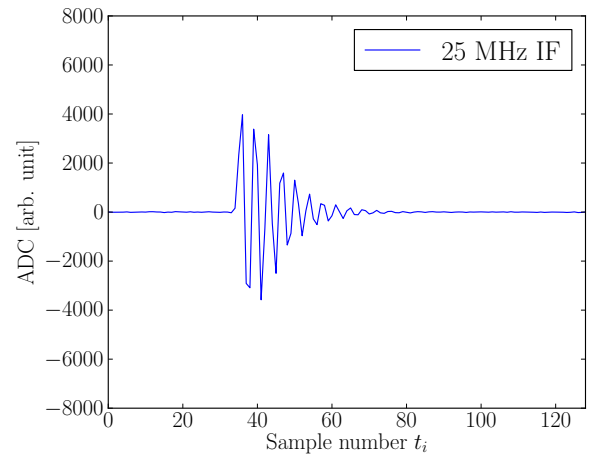


Homodyne processing digitized Signal (Zero IF signal)



Digital signal processing





Technique		# of parameters	Parameters
Single point	To sample at single point	1	t_{samp}
Filter	Digitally filtering the *I/Q* waveform before sampling	2	$\Delta f_{\mathrm{homo}}, t_{\mathrm{samp}}$
Integration	Integrating	2	$t_{\mathrm{int},0}, t_{\mathrm{int},1}$
DDC	Digital down-conversion (Digital mixer, Digital LO, digital filter)	3	$\omega_{\mathrm{DDC}}, \Delta f_{\mathrm{DDC}}, t_{\mathrm{DDC}}$

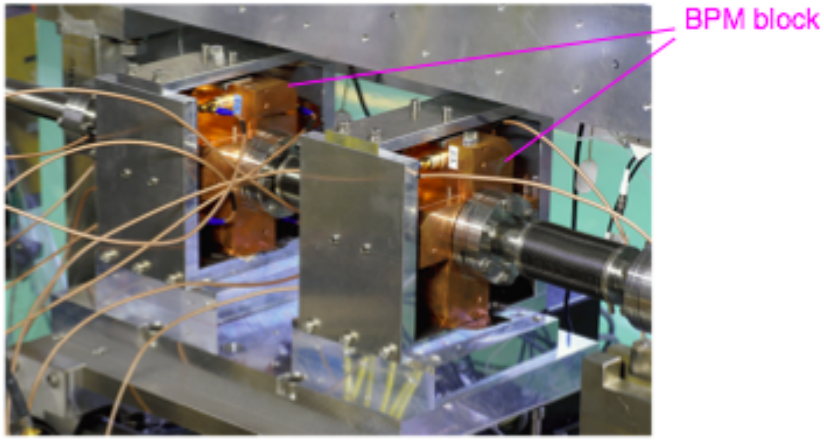
Calibration system

Previous measurement system

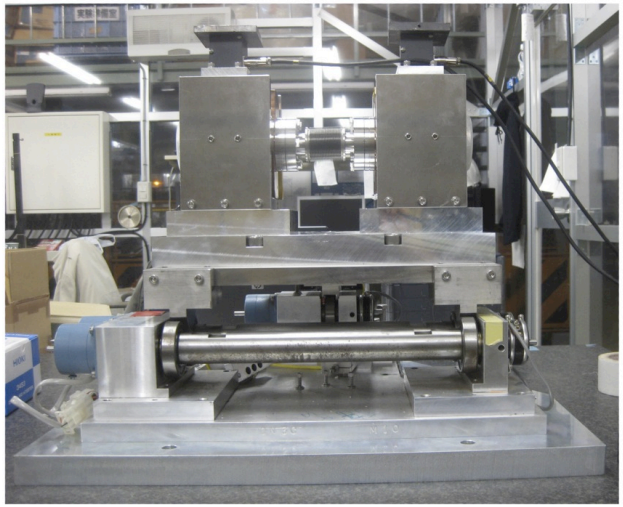
- No mover system to avoid loss of mechanical stability
- Steering magnets used to control beam position
- Precise stripline BPMs, wire scanners were used to determine an absolute position reference
- Possible to do exactly same way as Honda-san

Current measurement system

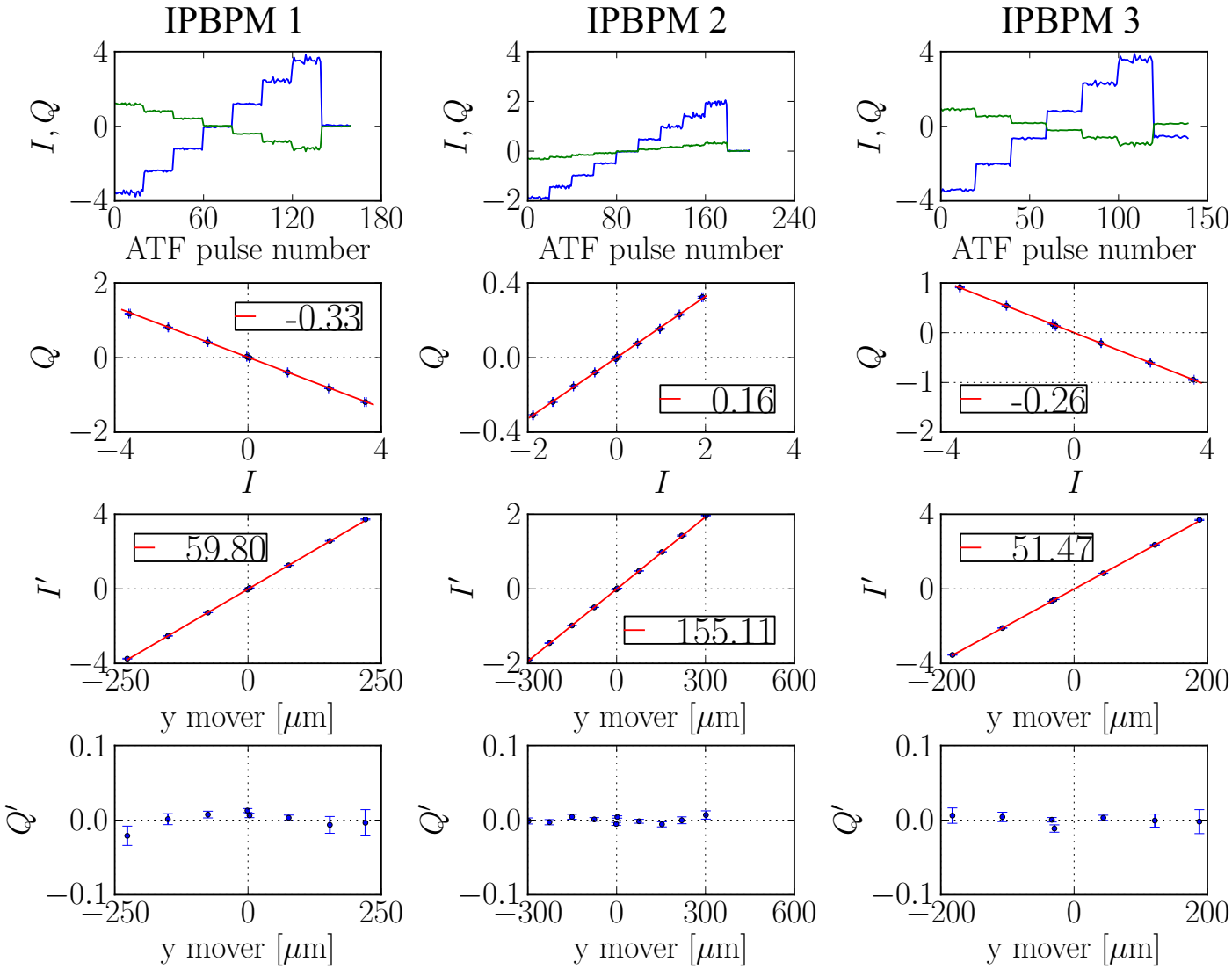
- Impossible to do exactly same way as previously
- Used mover (+- 60~ +- 200 um)
  - Developed and used for the FFTB
  - Horizontal/vertical : 2 um precision with 0.04 um resolution
  - Roll : 3 – 5 urad
- Mechanical vibration
  - Relative motion between two BPM blocks ~ 1.4 nm at acceleration frequency (1.56 Hz)



Y. Inoue *et al.*, PhysRevSTAB.11.062801

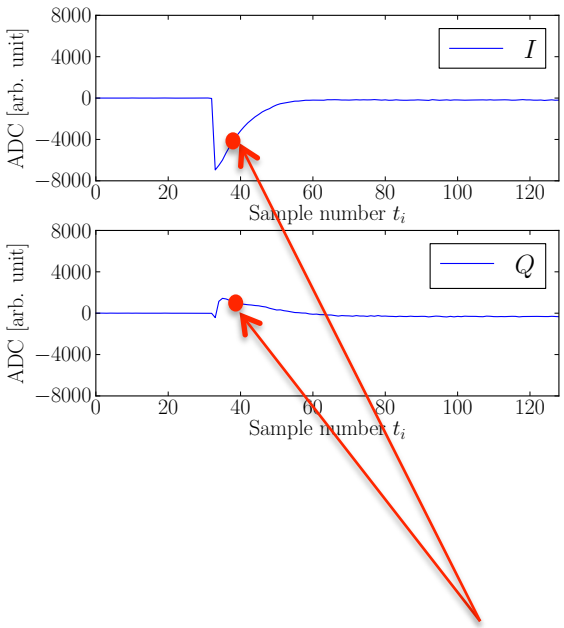


Calibration

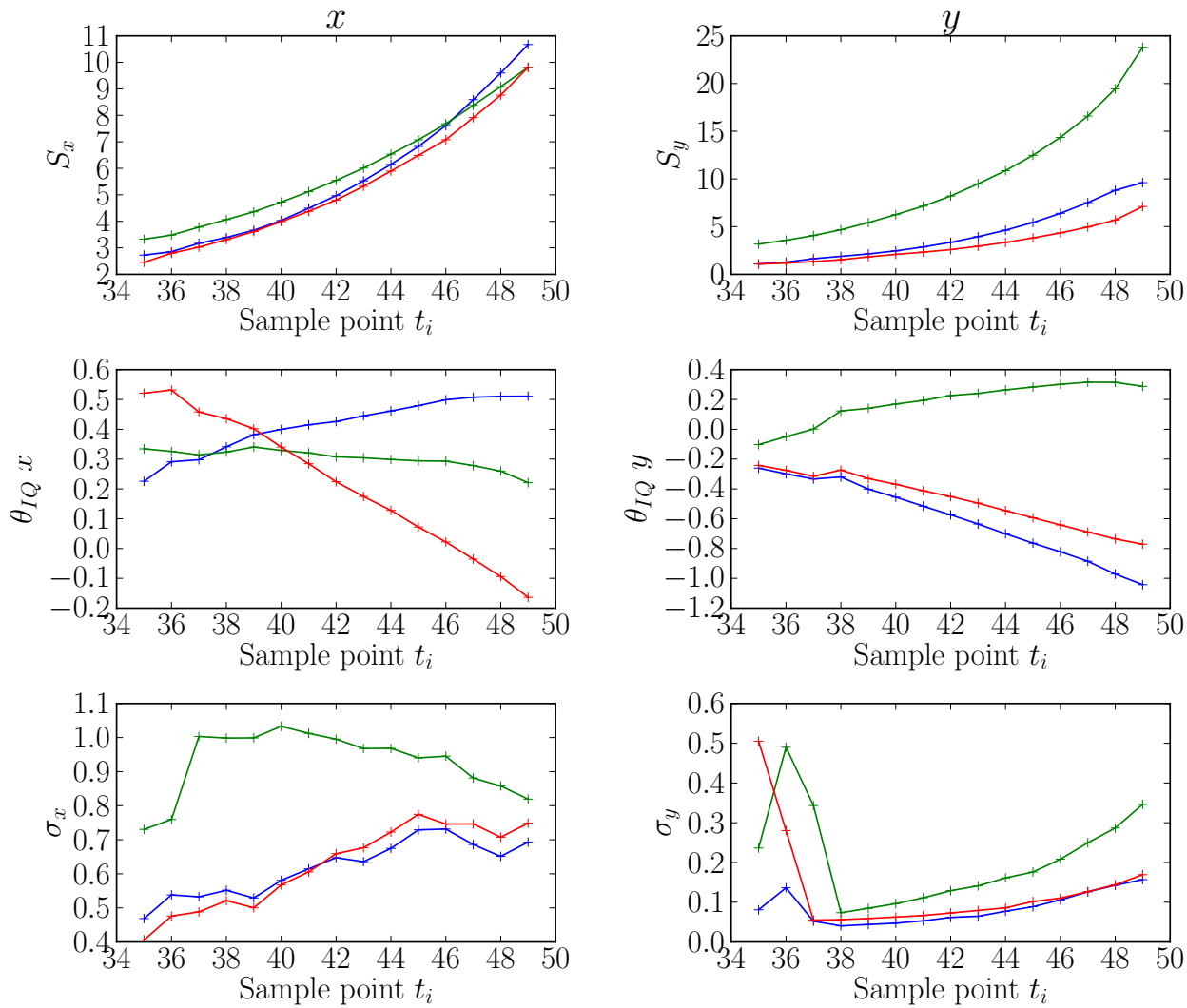


- Homodyne
- With 30 dB attenuator
- Each digital signal processing techniques show similar performance
- Heterodyne shows similar performance

Parameter optimization

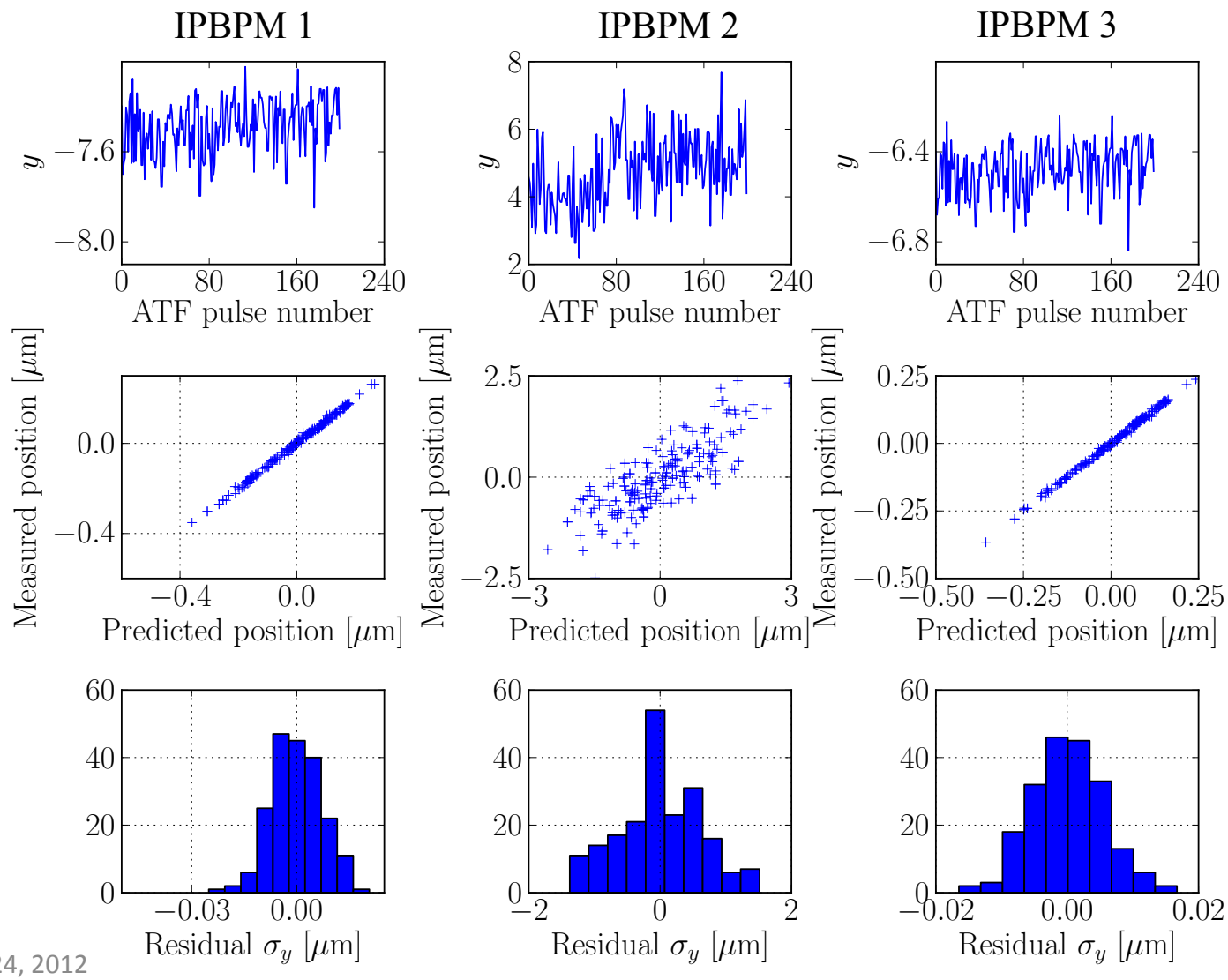


Sample point



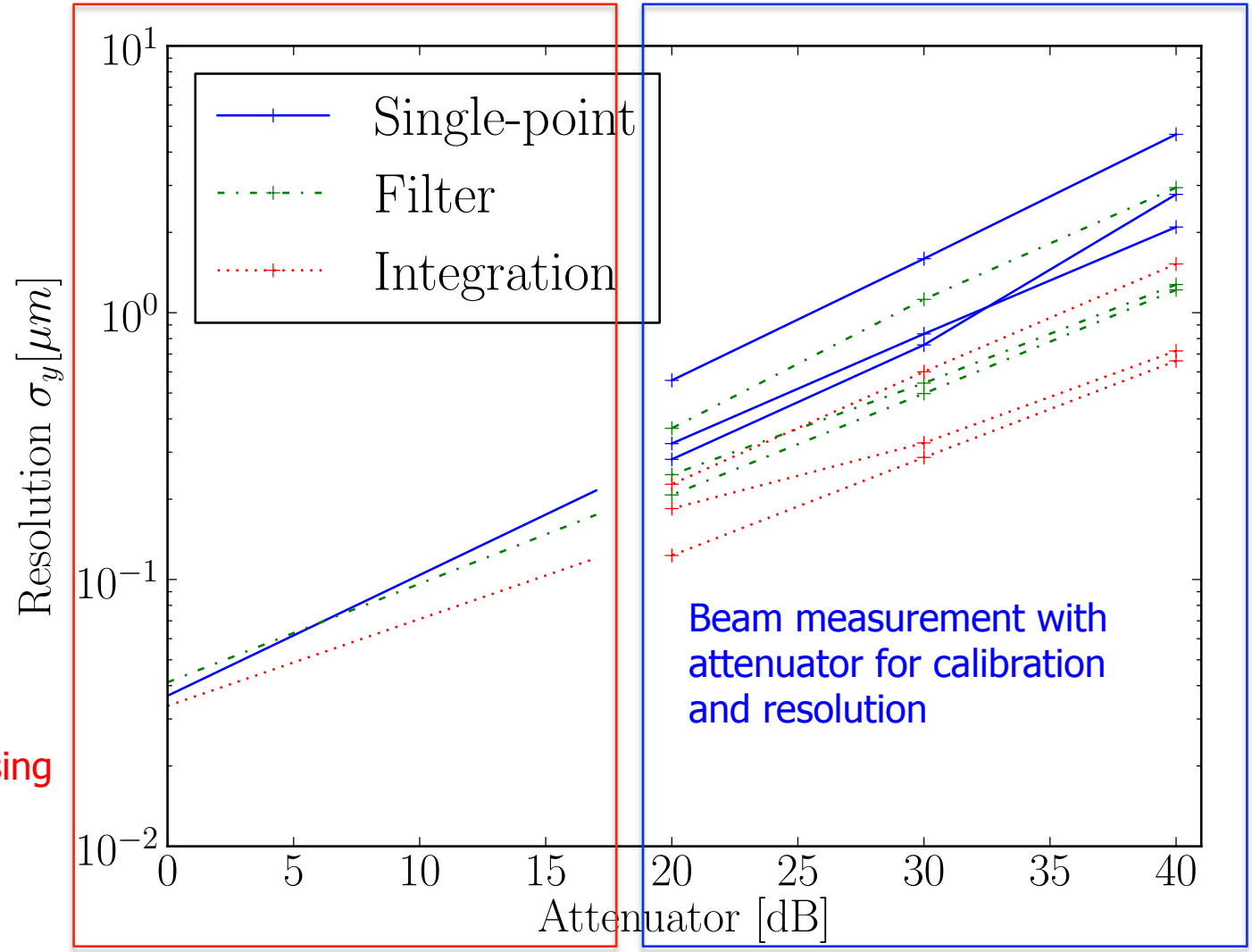
SVD method was used for the position resolution calculation

IPBPM triplet resolution control plot



Homodyne
(Single point)

Results



Extrapolated resolution from measurements using IPBPM 1 and 3

Geometrical resolution factor

- Can be determined using error propagation from relative position between three cavities

$$\sigma_{y,\mathrm{pred}}^2 = \left(\frac{s_2 - s_1}{s_3 - s_1}\right)^2 \left(\frac{\partial y_{2,\mathrm{pred}}}{\partial y_3}\right)^2 \sigma_{y_3}^2 + \left(\frac{s_3 - s_2}{s_3 - s_1}\right)^2 \left(\frac{\partial y_{2,\mathrm{pred}}}{\partial y_1}^2\right)^2 \sigma_{y_1}^2$$

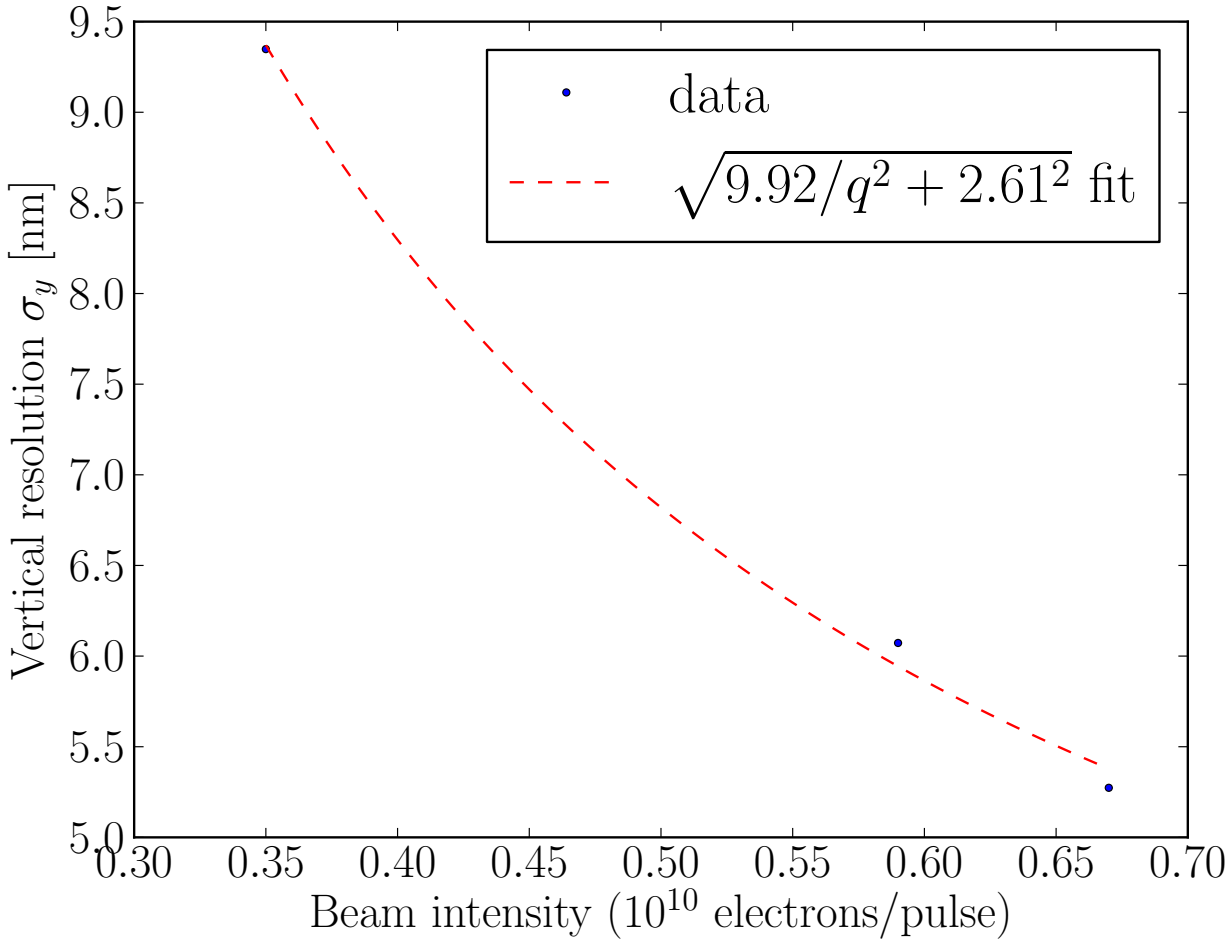
Assuming, $\sigma_{y1} \approx \sigma_{y_2} \approx \sigma_{y3}$

$$\sigma_{y,\mathrm{pred}}^2 = \left(\frac{s_2 - s_1}{s_3 - s_1}\right)^2 + \left(\frac{s_3 - s_2}{s_3 - s_1}\right)^2$$

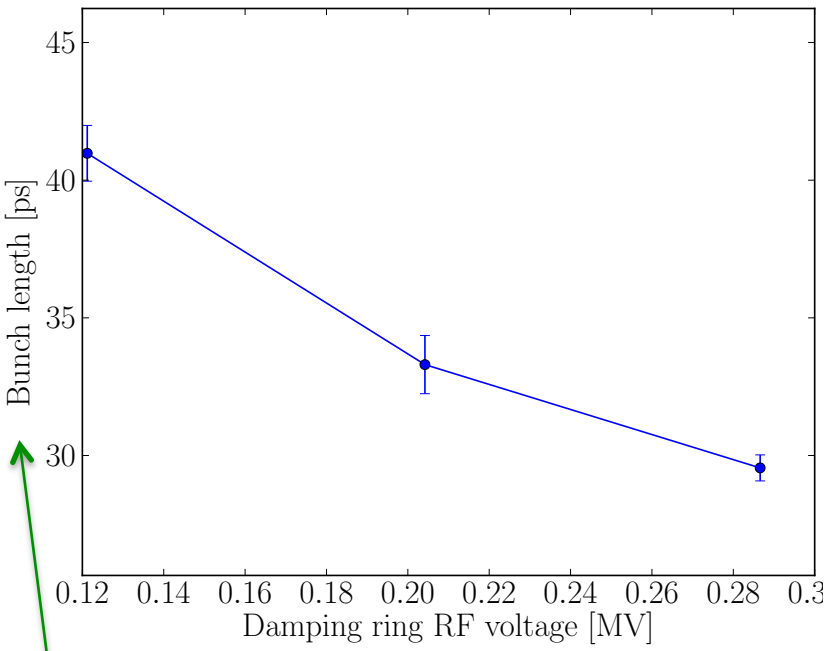
$$S_2 - S_1 = 164, S_3 - S_2 = 76, S_3 - S_1 = 240$$

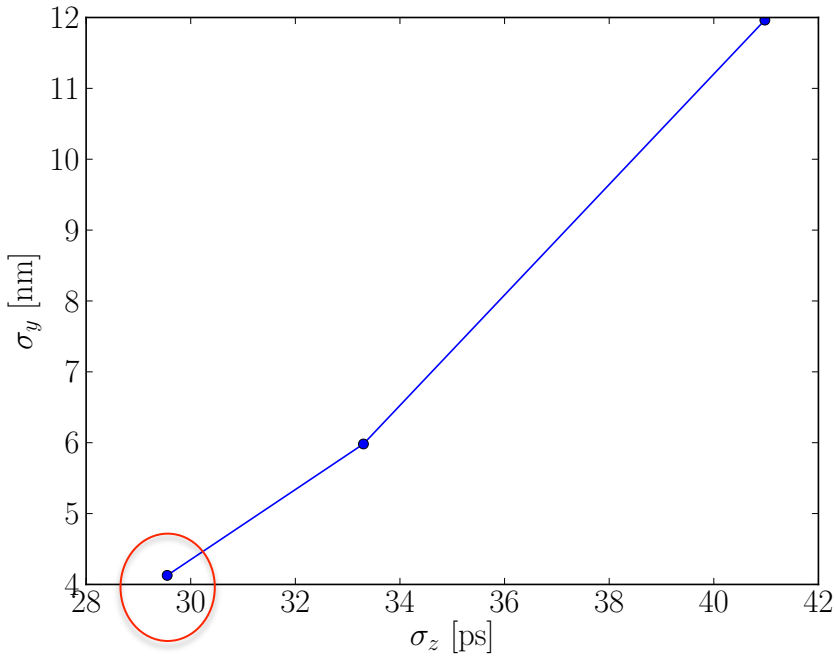
Geometrical factor : 0.753

Charge effect



Bunch length effect

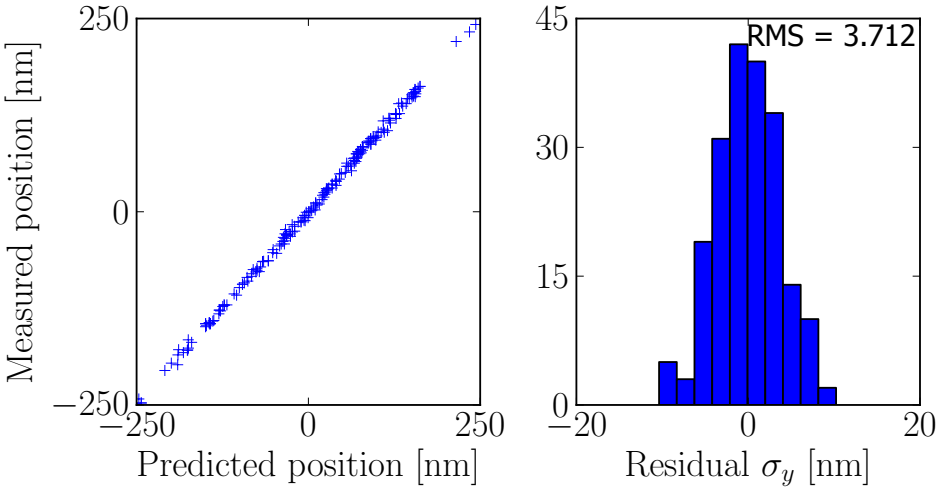




Measured using streak camera

Tried to keep same charge
Checked the beam charge using ICT

Results



N dB ext : N dB attenuator for calibration and resolution

N dB : N dB attenuator for calibration and 0 dB for resolution

Charge > 0.70 10^{10} electron/pulse

(Multiplied by geometrical factor)

Technique	40 dB ext	30 dB ext	20 dB ext	40 dB	30 dB	20 dB
Single point	11.747	15.311	17.695	7.004	30.440	4.128
Filter	4.202	5.843	7.803	2.905	31.086	2.715
Integration	5.591	7.096	9.864	3.983	26.373	2.795
DDC	-	19.384	14.955	27.758	13.699	20.571

Larger jitter : < 3 um (30 times larger than 1st week) vertical direction

Charge ~ 0.42 10^{10} electron/pulse

Summary

- High position sensitivity cavity BPMs system tested for interaction region at ATF2
- Homodyne/Heterodyne signal processing methods used
- Different digital signal processing techniques applied
  - Single point sampling, filtering, integration, DDC
- Resolution in region 4 to 20 nm with attenuators
- Less than 10 nm without attenuators and extrapolated scale factor

- Hard to compare homodyne/heterodyne directly due to the beam condition week by week
- The position resolution was consistently smaller for homodyne system measurement (1st week)